



Heart Rate Variability and Erectile Function in Younger Men: A Pilot Study

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Abstract

Erectile dysfunction (ED) in younger men is an increasing concern. In middle aged and older men, ED was related to lower resting heart rate variability (HRV), but research in younger men is lacking. The present study examined, in a nonclinical sample of 105 men between 18 and 39 years, the association of ED with several parameters of resting HRV. Scores of the 5-item version of the International Index of Erectile Function (IIEF-5) below 22 were considered as indicating ED. Eighteen men (17.1%) reported ED (mild in 16, mild to moderate in 2). Welch's tests revealed that ED was associated with lower low-frequency power (LF), lower high-frequency power (HF), lower standard deviation of interbeat intervals, and lower standard deviation of the heart rate, which is influenced by both sympathetic and parasympathetic activity. After removing outliers, ED was unrelated to HF. In younger men, erections might be facilitated by a combination of higher parasympathetic tone and relatively higher sympathetic tone in the heart, as indicated by LF and greater standard deviation of the heart rate, a largely overlooked parameter in HRV research.

Keywords Heart rate variability · Standard deviation of the heart rate · Erectile dysfunction · Younger men

Erectile dysfunction (ED) in younger men is an increasingly recognized problem (Capogrosso et al. 2013, 2016, 2019; Dattatrya et al. 2015; Nguyen et al. 2017; Myakonatis et al. 2018; Pozzi et al. 2018; Rastrelli and Maggi 2017; Reed-Maldonado and Lue 2016; Yao et al. 2018). Empirical evidence points to a growing incidence of ED complaints in men younger than 40 years (Rastrelli and Maggi 2017; Capogrosso et al. 2013, 2019). Therefore, it is important to study physiological correlates and risk factors in this population.

A psychophysiological correlate of ED in middle aged and older men is lower heart rate variability (HRV). Specifically, middle aged and older men with ED were shown to have lower high-frequency HRV (HF) or higher low-to-high frequency HRV ratio (LF/HF) than controls (Chen et al. 2009; Dogru et al. 2008; Lee et al. 2011). This suggests that,

at least in this age range, ED is associated with lower cardiac parasympathetic tone or greater sympathovagal imbalance as reflected in greater predominance of sympathetic over parasympathetic tone in the heart. This is confirmed by another study showing that middle aged and older men with ED had lower RR ratio (30:15), an index of parasympathetic-mediated HRV (Stuckey et al. 2007). In middle aged and older men, conflicting findings were reported regarding the associations of ED with low-frequency power HRV (LF), which is influenced by both sympathetic and parasympathetic activity (Chen et al. 2009; Dogru et al. 2008; Lee et al. 2011).

It was suggested that lower resting parasympathetic-mediated HRV is a sign of impairment in nitric oxide release. In the absence of adequate amounts of nitric oxide, penile vasodilation is insufficient for attaining or maintaining erections (Stuckey et al. 2007). Impaired nitric oxide release could be present in cases of excessive stress, depression, anxiety disorders, and many physical disorders, such as diabetes, hypertension, and cardiovascular diseases. These conditions have been associated with both ED (Capogrosso et al. 2016; Nguyen et al. 2017; Pozzi et al. 2018; Rastrelli and Maggi 2017) and lower resting HRV (Kemp and Quintana 2013; Lehrer et al. 2020; McCraty and Shaffer 2015; Thayer and Lane 2007; Thayers et al. 2012). This suggests that ED

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might be related to many physical and psychological disease processes partly by means of impaired release of nitric oxide that reflects on lower cardiac parasympathetic tone (Stuckey et al. 2007).

The relationships between HRV and sexual function have been less studied in younger men. In a nonclinical laboratory study with young men (mean age = 20.15, $SD = 2.52$), greater HF and lower LF/HF correlated with greater erectile tumescence responses to erotica (Harte 2013), but in another laboratory study with heavy smokers including many young men (age range: 23–58; mean age = 38.27, $SD = 10.62$), those who stopped smoking had improvements in erectile potency in response to erotica that were not explained by increases in HF or reductions in LF/HF, but rather by increases in LF (Harte and Meston 2013). This suggests that a combination of cardiac sympathetic and parasympathetic tone also has an important role in the erectile potency of younger men. Additionally, it was found that, among younger men, greater frequency of vaginal intercourse orgasms did not correlate with HF nor LF, but correlated positively with greater standard deviation (SD) of the heart rate (HR) (Costa and Brody 2012), which reflects increases in activation of both sympathetic and parasympathetic branches (Moser et al. 1994).

Given the potential of HRV feedback in ameliorating health conditions associated with ED (Lehrer et al. 2020), it is important to have a better understanding of the relationship between HRV and ED among younger men. Thus, the aim of the present study was to examine, in younger men (between 18 and 39 years), the associations of ED with HRV parameters that have been associated with sexual function.

Materials and Methods

Participants

All participants were from the Lisbon area (Portugal) and were recruited through the local university participant pool between 2013 and 2020 after taking part in four studies on psychological and psychophysiological factors in sexual behavior. All the four studies were retrospective, and received the approval of the Ethics Committee of the university where they were conducted. The sample is nonclinical and was obtained from the groups of sexually active men for whom there were data on HRV and erectile function assessed by the 5-item version of the International Index of Erectile Function (IIEF-5). Inclusion criteria consisted of the following: under the age of 40, heterosexual orientation, and not using prescription medications that could interfere with erection. The ED status was determined by IIEF-5 scores below 22 (Rosen et al. 1999). Thus, the final sample consisted of 105 Portuguese heterosexual men between 18 and 39 years, of which 18 (17.1%) had IIEF-5 scores indicating

ED. Sixteen reported symptoms of mild ED (all scoring between 19 and 21) and two reported symptoms of mild to moderate ED (scoring between 13 and 18).

Medical conditions were assessed by self-report, and were reported by nine participants: hypertension (two cases), type-1 diabetes (two cases), hypothyroidism, obsessive-compulsive disorder, attention-deficit/hyperactivity disorder (two cases), and alpha thalassemia. We did not exclude these participants, because physical and mental disorders are apparently common in younger men with ED and thus they may be part of the causal chain linking ED and lower HRV in this population (Capogrosso et al. 2016; Nguyen et al. 2017; Pozzi et al. 2018; Rastrelli and Maggi 2017). The group of men having these disorders was not significantly more likely to have ED: medical conditions were present in two participants (11%) in the group with ED and in seven participants (8%) in the group without ED, $\chi^2 = 0.179$, $p = 0.672$.

Table 1 displays descriptive statistics.

Measures

The presence of ED was determined by scores of 21 or less in the Portuguese version of the 5-item version of International Index of Erectile Function (IIEF-5; Pais Ribeiro and Santos 2007; Rosen et al. 1999).

ECG was recorded by an MP150 BIOPAC system using the software Acqknowledge 4.0 (BIOPAC Systems, Inc) and three Ag–AgCl electrodes applied to both wrists and one

Table 1 Demographics

	With ED ^a <i>N</i> = 18 Mean (<i>SD</i>) or %	Without ED ^b <i>N</i> = 87 Mean (<i>SD</i>) or %
Age (years)	26.72 (7.25)	23.41 (4.03)
<i>Education</i>		
High school	5.6	4.6
University attendance	33.3	49.4
University degree	61.1	46.0
<i>Occupation</i>		
University student	55.6	67.8
Employed	44.4	31.0
Unemployed	0.0	1.1
<i>Relationship characteristics</i>		
With regular sexual partner	66.7	88.5
Cohabiting	11.1	19.5
Relationship duration (months) ²	21.18 (19.93)	35.90 (32.66)

SD standard deviation

^aED defined as scores of 21 or less in the 5-item version of the International Index of Erectile Function (IIEF-5)

^bApplies only to those with a regular sexual partner: *N* = 89 (84.8%)

ankle. Parameters of HRV were calculated by the software HRV analysis (<http://kubios.uef.fi>). In order to optimize the R-R interval data for HRV analysis (www.biopac.com), the ECG was treated according to the guidelines of BIOPAC Systems, Inc. The sample acquisition rate was 1.000 samples per second. The ECG was filtered (band pass) between 0.5 and 3.5 Hz with 8.000 coefficients. After applying the template correlation function, a tachogram was created and visually inspected for detection of artefacts. From a 5-min resting period several frequency and time domains of HRV were calculated. The frequency domain measures included in the study were the low frequency power (LF) and the high frequency power (HF). The LF and HF are calculated by means of power spectral analysis, by which the variance of the interbeat intervals is distributed across different frequency bands. The LF range expresses the variance of interbeat intervals occurring between 0.04 and 0.15 Hz. The HF range expresses the variance of interbeat intervals occurring between 0.15 and 0.40 Hz. The LF component is influenced by combinations of sympathetic and parasympathetic activity, but mostly by parasympathetic activity. Variability of heart rate in the LF band appears to be an index of baroreceptor function (Goldstein et al. 2011; Reyes del Paso et al. 2013). The HF is dependent on parasympathetic activity and is a widely used measure of cardiac vagal tone. It reflects changes in duration of the cardiac cycles modulated by the respiratory rhythm: the heart accelerates during inspiration and decelerates during expiration (respiratory sinus arrhythmia). Also see Kromenacher et al. (2018) who reported that respiratory rates below nine breaths per minute are associated with changes in the duration of the cardiac cycles that occur in the LF band, and that this process is parasympathetically driven. Additionally, we calculated the LF/HF ratio, which is commonly interpreted as a measure of sympathovagal imbalance with greater values indicating greater imbalance with predominance of sympathetic activity. However, this interpretation has been challenged (Reyes del Paso et al. 2013).

The time domain measures included the standard deviation of the interbeat intervals (SDNN) and the standard deviation (SD) of the heart rate (HR) averaged across the five minutes period. The SDNN expresses mainly parasympathetic activity (Polanczyk et al. 1998; Silva et al. 2017), but is influenced by sympathetic activity to some extent (Silva et al. 2017). The SD of HR has been a rather overlooked HRV parameter. Moser et al. (1994) reported that it is increased by both sympathetic and parasympathetic activation. In a study that compared differential correlations of HR with SD of HR and other HRV parameters (Gomes et al. 2019), it was found that both SDNN and LF correlated inversely with HR, which is consistent with other studies (Kazmi et al. 2016; Sacha and Pluta 2005). However, the SD of HR correlated nonsignificantly but *directly* with HR

(Gomes et al. 2019), suggesting that the SD of HR is more influenced by sympathetic activity than SDNN and LF.

Procedure

Prior to providing written informed consent, all participants were assured that the data are anonymous and confidential, that they could leave the experiment at any time they wished, and that they could leave blank the questions that they did not want to answer.

In the four laboratory studies from which the present sample was taken, participants provided a saliva sample for hormonal assays and performed a tactile sensitivity task with Von Frey microfilaments immediately before the ECG measurements. During the ECG measurement participants were sitting alone in an isolated room. This was followed by a heartbeat detection task, after which, participants underwent an induction of sexual fantasy (first study), were shown a sexually explicit video or a romantic movie scene video (second study), or were shown a romantic movie scene (third study). After these tasks, participants provided a second saliva sample, and immediately afterwards, the questionnaire battery with the IIEF-5 was completed. This battery was composed of questionnaires on personality, mood, and sexual behavior, among which the IIEF-5 was inserted. In the fourth study, participants started completing the questionnaire battery after the heartbeat detection task. In the four studies, participants were alone when they completed the questionnaires in the same private room where the ECG measurement was taken.

Statistical Analyses

Because the groups with and without ED had unequal sample sizes with the ED group being much smaller, we compared them with unequal variance *t* tests (Welch's tests), which are more reliable in these circumstances (Ruxton 2006).

Results

Men with ED were less likely to have a regular sexual partner ($\chi^2 = 5.51$, $p = 0.019$), but were not less likely to cohabit ($\chi^2 = 0.76$, $p = 0.398$). Among the subgroup with a regular partner ($N = 89$), there was a marginal tendency for those with ED having relationships of shorter duration; Welch's test = 2.01, $df = 21.20$, $p = 0.057$ (see Table 1). The groups with and without ED did not differ in age; Welch's test = 1.75, $df = 20.52$, $p = 0.096$.

The groups with and without regular partner did not differ in any HRV parameter (all $p > 0.09$), but the partnered group had slower HR ($M = 80.16$, $SD = 13.96$) than the unpartnered

one ($M=88.94$, $SD=13.19$), Welch's test=2.43, $df=21.51$, $p=0.024$.

Table 2 shows the intercorrelations between HR and HRV parameters expressing different contributions of sympathetic tone. Notably, the SD of HR was the only HRV parameter not inversely correlated with HR; indeed it had a nonsignificant positive correlation with HR. Also, SD of the HR correlated much more strongly with LF and SDNN than with HF. Moreover, LF correlated more strongly with HF than the SD of HR did. All this confirms the greater contribution of sympathetic tone for the SD of HR (Moser et al. 1994), a contribution of sympathetic activity apparently greater than that of LF.

As depicted in Table 3, Welch's tests show that the group with ED had lower SD of HR, lower SDNN, lower LF, and lower HF. We repeated the analyses removing the outliers in HRV distributions (more than three SD s above the mean). After removing three outliers in the HF distribution, the group with ED had a nonsignificant trend to have lower HF (Welch's test = 1.88, $df=34.41$, $p=0.069$). After removing two outliers in the LF distribution, the group with ED continued to have lower LF (Welch's test = 2.79, $df=40.14$, $p=0.008$). After removing two outliers in the distribution of the SD of HR, the group with ED continued to have lower SD of HR (Welch's test = 2.19, $df=24.08$, $p=0.038$). After removing one outlier in the SDNN distribution, the group

with ED continued to have lower SDNN with a marginally significant difference (Welch's test = 2.03, $df=26.86$; $p=0.052$).

Discussion

In the present study in a nonclinical sample of Portuguese men younger than 40, there were 17.1% reporting symptoms of ED, mild in all but two cases. This figure is congruent with other studies indicating that ED in younger men is common (Capogrosso et al. 2013, 2016; Capogrosso et al. 2019; Dattatrya et al. 2015; Nguyen et al. 2017; Myakontis et al. 2018; Pozzi et al. 2018; Rastrelli and Maggi 2017; Reed-Maldonado and Lue 2016; Yao et al. 2018).

We found that the group with ED had lower SD of HR, lower SDNN, lower LF, and lower HF, but after removing outliers, HF was not significantly different between groups. Our results seem consonant with others finding a relationship between ED and lower LF (Chen et al. 2009; Harte and Meston 2013); this suggests that a mix of greater sympathetic and parasympathetic tone in the heart can favor erectile tumescence.

Cardiac parasympathetic tone might be part of a mechanism related to better vascular function, which is important for erections (Stuckey et al. 2007). Also, cardiac parasympathetic tone has been related to better attention regulation in response to emotional stimuli (Park and Thayer 2014; Quintana et al. 2012) and better couple interaction and communication (Coutinho et al. 2017), all of which could facilitate sexual contacts and thereby erections.

However, we found that ED was associated with LF and SD of HR, two HRV parameters influenced by sympathetic activity. These relationships remained after exclusion of outliers, which did not happen with HF. This leads to the question if coupling between parasympathetic activity and moderate sympathetic activity adds an extra benefit to erectile function, and if so, by what means. In fact, research in men and women indicates that a moderate amount of sympathetic activity favors genital arousal (Guay et al. 2002;

Table 2 Intercorrelations between heart rate and heart rate variability parameters (total sample; $N=105$)

	HR	SDNN	SD of HR	LF
SDNN	-.63***			
SD of HR	.07	.68***	–	
LF	-.38***	.86***	.68***	–
HF	-.44***	.71***	.40***	.53***

HR heart rate, SDNN standard deviation of interbeat intervals, SD of HR standard deviation of the heart rate, LF low-frequency power (autoregressive modeling), HF high-frequency power (autoregressive modeling)

*** $p < .001$

Table 3 Unequal variance t -tests (Welch's tests) comparing those with and without erectile dysfunction

	With ED Mean (SD)	Without ED Mean (SD)	Welch's test (df)	p
HR (bpm)	81.04 (13.88)	81.59 (14.28)	.15 (25.02)	.880
SDNN (ms)	44.59 (19.13)	55.73 (22.77)	2.17 (27.95)	.039
SD of HR (bpm)	4.64 (1.71)	5.74 (1.83)	2.45 (25.77)	.022
LF (ms^2)	870.09 (689.77)	1578.91 (1447.04)	3.15 (53.31)	.003
HF (ms^2)	345.16 (299.97)	607.63 (714.28)	2.52 (63.11)	.014
LF/HF	3.21 (1.61)	3.91 (2.83)	1.43 (42.21)	.160

HR heart rate, SDNN standard deviation of interbeat intervals, SD of HR standard deviation of the heart rate, LF low-frequency power (autoregressive modeling), HF high-frequency power (autoregressive modeling), LF/HF low-to-high frequency ratio, SD standard deviation, df degrees of freedom

Meston 2000; Morales 2000; Pfau 2009), and inhibition of sympathetic activity increases risk of ED (Manolis et al. 2020) and reduces female genital arousal in response to erotica (Meston 2000).

While the parasympathetic involvement in the physiology of erection is well known, it is unclear how the sympathetic branch could increase erectile tumescence. One possibility is that the sympathetic activation may not have a direct effect on the physiology of erection, but rather an indirect effect by means of increasing attentional and emotional engagement with the sources of sexual stimulation, thereby avoiding distracting thoughts that inhibit genital arousal. In support of this notion, both higher parasympathetic and higher sympathetic activity were independently related to greater selective attention (Giuliano et al. 2008). Experimental research shows that the attractiveness of opposite-sex persons is enhanced by thrilling situations likely to trigger sympathetic activation (Barlow et al. 1983; Meston and Frohlich 2003; Dutton and Aron 1974), which is consistent the sympathetic branch enhancing attentional engagement with sexually rewarding stimuli. In addition, research in rodents shows that sympathetic activation increases approaches to the opposite sex, and sympathetic inhibition has the opposite effect (Meston 2000; Pfau 2009). As such, it is possible that a moderately higher sympathetic tone could lead to propensity to be more attentionally focused and attracted by partners, as well as with greater motivation to initiate approaching behaviors due to enhanced blood flow to the skeletal muscles. All this would likely result in greater genital responses due to greater sensorimotor immersion in the experience of the sexual activity.

Indirect evidence that the coupling between sympathetic and parasympathetic cardiac activation has a role in perceiving others as more attractive comes from research on effects of alcohol, which is commonly acknowledged as facilitator of sexual desire. Moderate doses of alcohol were found to increase attractiveness of faces (Chen et al. 2014; Parker et al. 2008), muscle sympathetic nerve activity, heart rate, and LF while decreasing HF (Spaak et al. 2008, 2010).

However, other research suggests that sympathetic activation inhibits erections (Hale and Strassberg 1990). It is possible that there are moderating factors in the association of LF and SD of HR with erectile function, but given that the studies have different methodologies of stimulating sympathetic activity, it is not clear if the inhibitory effects noted by Hale and Strassberg (1990) were elicited by a too high sympathetic activation.

Other explanation for the relationship between ED and lower LF is suggested by LF being an index of baroreceptor function. Mather and Thayer (2018) noted that the baroreflex feedback loop has the same frequency as the respiratory cycle during slow breathing at around 0.1 Hz (one respiratory cycle at each 10 s). They proposed that

this physiological resonance between the two coordinated biological rhythms creates high amplitude oscillations in heart rate that promote functional connectivity in brain regions involved in emotional regulation, such as connectivity between prefrontal cortex, amygdala, insula, and cingulate cortex. In support of this view, patients with psychogenic ED were found to have impaired functional connectivity between prefrontal and posterior cingulate cortices (Cera et al. 2014; Yin et al. 2020) and impaired functional connectivity between prefrontal cortex and anterior insula (Wang et al. 2017). Psychogenic ED patients were also found to have impaired prefrontal-amygdala structural connectivity (Chen et al. 2018). The relationship between ED and emotional dysregulation (negative mood) is well documented (Nguyen et al. 2017).

Additionally, the insula and the amygdala appear to have a role in baroreceptor function through its connections to the nucleus of the solitary tract, which receives information from baroreflex neurons (Henderson et al. 2004). Given that abnormalities in insula and amygdala were related to psychogenic ED (Chen et al. 2018; Jin et al. 2018), it is possible that the relation between lower LF and ED is at least partly explained by baroreflex dysfunction. There is lack of research in this regard. Interestingly, one study found that lack of penile–vaginal intercourse was associated with greater increases in blood pressure in response to social stress (Brody 2006), which is congruent with the possibility that baroreflex dysfunction is related to ED. This raises questions for future research.

The SD of HR has been largely overlooked in HRV research, perhaps because it is very influenced by sympathetic activity, and because of that it was not considered a reliable prognostic marker of cardiovascular health (Moser et al. 1994). Research is needed in this regard. Our findings and those of Gomes and colleagues (2019) are in line with the notion that the SD of HR is influenced by sympathetic activity to greater extent than LF and SDNN. Notably, greater resting SD of HR correlated with greater frequency of penile–vaginal intercourse in men and women (Costa and Brody 2012; Brody and Preut 2003; Brody et al. 2000; Gomes et al. 2019), and more likelihood of orgasm through penile–vaginal intercourse in women (Costa and Brody 2012). Lower HRV (especially SDNN) has been related to lower sexual arousal in women (Stanton et al. 2015, 2019), but there is lack of research on the role of the SD of HR in female sexual function (Costa and Brody 2015).

A limitation of the study was the small sample size, especially in the group reporting symptoms of ED. In order to compare the groups in our study, we used the Welch's test, which is more robust against the problem posed by unequal variances when we need to compare groups of unequal size in small samples (Ruxton 2006).

There are several limitations of the present pilot study that must be addressed in future research. The present results must be validated by larger studies of patients with ED in order to make any conclusions or treatment recommendations. For determining ED status, we used solely IIEF-5 scores. Future studies should include questions on symptom duration or diagnoses of ED based on specialist confirmation. Future studies could also do a more thorough medical screening including in-depth interviews and medical exams to detect comorbid conditions. This will allow a better understanding on how particular psychological and physical disorders influence the relations between erectile function and HRV parameters.

In conclusion, in a pilot study with a nonclinical sample of men younger than 40, we found that ED was related to lower SDNN, lower LF and lower SD of HR, a largely overlooked HRV parameter that expresses a combination of sympathetic and parasympathetic activity.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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